THE TRAVEL OF CIRCULAR DEPRESSIONS AND TORNADOES AND THE RELATION OF PRESSURE TO WIND FOR CIRCULAR ISOBARS.

By Sir NAPIER SHAW.

This memoir is a continuation of the study of traveling cyclonic depressions which was begun in the Life History of Surface Air Currents (M. O. 174), published in 1906. Those who are accustomed to study weather maps have generally formed the idea that the typical cyclonic depression which is represented by a group of concentric circular isobars on the map is the base of a column of air whirling about an axis and traveling over the country. Without any special examination of the question the foot of the axis of the whirl has been supposed to be the center of the circle of isobars, and the moving column has been supposed to be fed on all sides by air moving along spiral curves to the axis. These views as applied to traveling depressions, are really erroneous.

It was shown in the Life History that in actual cases the air was fed into the cyclone on the right front, and, as a rule, in spite of appearance, did not reach the axis in the end, but was thrown out again from the rear of the cyclone on the same side, so that the apparent inward spiral movement was in those cases simply deceptive.

The new investigation began by pointing out that there might be cases of revolving columns of air traveling over the country, the bases of which were not represented on the map by groups of circular isobars, but by the isobars of "a small secondary." The destructive small secondary of March 24, 1895, was identified as an example. The tornado in South Wales on October 27, 1913, was cited as another example, and it was generally concluded that traveling revolving columns of air were to be found as secondaries mainly in the southern parts of great cyclonic depressions, not at the centers of those depressions. The primary depression was thought to represent motion of a different kind. These conclusions were set out in a paper on Revolving Fluid in the Atmosphere before the Royal Society in June, 1917.

The present memoir recapitulates that paper and carries the study further by calling attention to certain propositions applicable to the case of what is called the "normal cyclone"; that is, one in which the velocity in rotation is proportional to the distance from the axis as it is in the case of a revolving solid. This normal cyclone is supposed to travel with a specified velocity which is provided for by the proper adjustment of the distribution of pressure.

It is explained that what may be called the center of winds, or the "kinematic center" of the motion; that is, the point round which the winds of a map would appear to circulate, is not the center of isobars, but a point some way from that center on the left of its line of motion. The paths of air would be those traced out by points attached to a horizontal circle, which has its center at the true center of permanent rotation (called the tornado center), and which rolls along the path of the kinematic center. The distance apart of the real center of rotation and the apparent or instantaneous center depends on the rate of rotation and the rate of travel: it may be in some cases 60 miles or more.

The center of isobars lies between the other two centers at a position which can also be calculated from the rate of rotation and the rate of travel by allowing for the distribution of pressure corresponding to each. The whole field of pressure will consist of the combination of the circular isobars representing the rotation, with the linear isobars representing a stream of air which would carry the rotating column along. The complete base of the revolving column will include any circular isobars shown on the map on the left-hand side of the path of the center, and a number of additional isobars formed of arcs of circles on the right hand side of the path of the center of the disk or circular base which fill up the area of the disk. Thus a spinning disk of air in a flowing stream of air would give to a map the appearance of winds circulating round a point on the left of its path, and the controlling pressure which would keep the system in being is a set of isobars centered round a different point the actual center of isobars on the map), also on the left. The position of the actual center of the disk itself would not attract attention at all. It would be somewhere in a set of curved isobars; and though its position could be accertained if the rate of travel were known, there is nothing special to mark it on the map.

It is on that account that the true position of the axis of rotation has never been suspected during the 60 years of the study of weather maps, yet the true position is a matter of great importance for the physics and dynamics of traveling cyclones. The physical processes of ascending air, rainfall, and the like should be thought of as referred to the center of the traveling disk, not to the point on the map which for the moment has no velocity; nor to the still more apparent center of isobars.

It is also shown that air in instantaneous rotation round a point will develop a similar circulation at successive points along a line on the map if it is pushed by a uniform field of pressure toward the right of the path which the center has to follow, and this may prove to be the operative cause of the travel of isobars in certain cases.. Any group of isobars which (apart from disturbance at the surface) are not in agreement with the actual winds are in a condition to travel like a cyclone, the direction and speed of travel depending upon the divergence between the actual winds and the winds computed from the isobars.—Meteorological Office Circular 25, June 24, 1918.

[1] Geophysical Memoirs, No. 12, British Meteorological Office, 1918, 4°, 44 pp., 5 pl., 2 figs.

THE RELATION OF WIND TO THE DISTRIBUTION OF BAROMETRIC PRESSURE. (MANUAL OF METEOROLOGY, PART IV.)

By Sir NAPIER SHAW.

Sir Napier Shaw's recently published work, on "the Relation of the Wind to the Distribution of Barometric Pressure," which comprises Part IV of a "Manual of Meteorology," is largely a summary of previous efforts and investigations in aerology.[2] In the preface, the author says: "It represents the progress made chiefly by those who have been associated in the work of the Meteorological Office in the past 20 years. * * * Our concern in this work is to present a summary * * * in the most handy form for conveying an idea of the information which is available."

The subject matter of the book proceeds logically from the observation of surface phenomena to those of the upper air, in order to establish, if possible, some relation between these surface phenomena and the processes which are taking place aloft. Particular emphasis is

[1] Cambridge, 1919, 4°, 160 pp., 4 pl.

[2] A review of this work by Gordon Dobson is published in the Quart. Jour. Roy. Meteorological Soc., July, 1919, vol. 45, pp. 262–264.

laid upon the importance of the work of G. I. Taylor[1] in eddy-motion in the atmosphere, and of the value of his coefficient of "eddy conductivity" in meteorological work. Frequent references are made to the work of Dines and Dobson with pilot balloons. In the concluding chapters he deals with the "revolving fluid of the atmosphere." The Meteorological Office has published[2] Sir Napier Shaw's previous work along this line, so that the material presented in the latter portion of the "manual" is a résumé of that to be found in the memoir.[3] —*C. L. M.*

THE TRAVELING CYCLONE.

By the late LORD RAYLEIGH.

(The London, Edinburgh, and Dublin, Phil. Mag., and Jour. of Sci., 6th Ser., No. 225, September, 1919, pp. 420–424.)

One of the most important questions in meteorology is the constitution of the traveling cyclone, for cyclones usually travel. Sir N. Shaw[4] says that "a velocity of 20 meters/second (44 miles per hour) for the center of a cyclonic depression is large but not unknown; a velocity of less than 10 meters/second may be regarded as smaller than the average. A tropical revolving storm usually travels at about 4 meters/second." He treats in detail the comparatively simple case where the motion (relative to the ground) is that of a solid body, whether a simple rotation, or such a rotation combined with a uniform translation; and he draws important conclusions which must find approximate application to traveling cyclones in general. One objection to regarding this case as typical is that, unless the rotating area is infinite, a discontinuity is involved at the distance from the center where it terminates. A more general treatment is desirable, which shall allow us to suppose a gradual falling off of rotation as the distance from the center increases; and I propose to take up the general problem in two dimensions, starting from the usual Eulerian equations as referred to uniformly rotating axes.[5]

Sir J. Larmor has added to Rayleigh's incomplete article a paraphrase, which closes as follows: "In any case, internal viscosity is negligible in meteorological problems. It is the friction against land or ocean, introducing turbulence which spreads upward, that disturbs and ultimately destroys the cyclonic system; and the high degree of permanence of the type of motion seems to permit that also to be left out of account. As remarked in the postscript, the changes of pressure arising from convection involve changes of density, which will modify the motion but perhaps slightly. There does not seem to be definite discordance with Dr. Jeffreys's detailed discussion."

ON TRAVELING ATMOSPHERIC DISTURBANCES.[6]

By HAROLD JEFFREYS.

[Author's summary.]

The geostrophic[7] relation between the wind and the surface pressure gradients is incapable of accounting for any variation whatever with time in the pressure distribution. All changes in this arise from those terms in the equations of motion that are neglected when the geostrophic relation is assumed. When these terms, which depend on the squares and differential coefficients of the velocities, are taken into account, it is found that an asymmetrical cyclone can move. It seems, however, from the low speed of travel of these depressions, that a simple superposition of a general pressure gradient on a rotating system must be compensated internally in some way, so as to reduce the asymmetry introduced. Thus the remarkable circularity of the isobars in a cyclone is seen to be a condition of its slow movement. It is indicated that the cyclone itself is a very special type of disturbance, in which the pressure, temperature, and velocity are so distributed as to make the wave tending to readjust it travel with extreme slowness; other types of disturbance spread out much more rapidly (with velocities of the order of that of sound) and are dissipated, and this fact is probably the reason why, [that] of all the irregularities possible, the cyclone is the most conspicuous, other forms dissipating before they can be observed.

[1] Eddy Motion in the Atmosphere, *Phil. Trans.*, 1915, vol. 215, pp. 1–26.
Skin Friction of the Wind on the Earth's Surface, *Proc. Roy. Soc.* Ser. A, 1916, vol. 92, pp. 196–199.
Phenomena Connected with Turbulence in the Lower Atmosphere, idem. 1918, vol. 94, pp. 137–155.
A discussion of these papers by Mr. Eric R. Miller will appear in the October issue of the REVIEW.

[2] Sir Napier Shaw: The Travel of Circular Depressions and Tornadoes and the Relation of Pressure to Wind for Circular Isobars Met. Off. *Geophysical Memoirs*, No. 12-1918.

[3] See Review, p. 643, above.

[4] Manual of Meteorology, Part iv, p. 121, Cambridge, 1919.

[5] Lamb's 'Hydrodynamics, par. 207, 1916.

[6] Phil. Mag., London, January, 1919, Ser. 6, 37: 1-8. See also Sci. Abs. March, 1919, pp. 92–93.

[7] *Geostrophic.*—"Let us call the one [component] due to the rotation of the earth the 'geostrophic' component, and the other due to the curvature of the path the 'cyclostrophic' component."—Gr. Brit. Met. Office, handbook, Weather Map and Glossary, London, 1918, p. 135.

CHARACTERISTICS OF THE FREE ATMOSPHERE.[1]

By W. H. DINES, F. R. S.

(Abstract.)

SYNOPSIS.—"This report was prepared in 1916, but on account of the war it was not then published." The subject is discussed under the following headings:

1. Methods and places of observation.
2. Amount and reliability of the material.
3. Mean temperatures and gradients.
4. The seasonal variation.
5. The daily temperature range.
6. The humidity.
7. The troposphere and stratosphere.
8. Pressure and density.
9. The motion of the free atmosphere.
10. Statistical data.
11. The connection between pressure and temperature.
12. The vertical temperature gradient and the value of H_s.

Appendix. The standard deviations of the density of the air from 1 to 13 kilometers, and the frequency of occurrence of deviations of given magnitude.

In general the paper deals with data and conclusions that had already been presented elsewhere, but they are here brought together into concise form, together with some of the more recent results. The reader is thus enabled to gain a comprehensive idea of the whole subject without having to consult several separate papers that have appeared from time to time in various publications.

1. *Methods and places of observation.*—For the most part the discussion is based upon results obtained in different parts of Europe, although equatorial and Canadian values are given in some of the tables and are briefly referred to in the text. In all cases the data were obtained by means of sounding and pilot balloons.

2. *Amount and reliability of the material.*—Practically 90 per cent of the balloons sent up in continental Europe are recovered; but in England, owing to the proximity of the sea, the loss averages about 35 per cent. Different sizes of balloons and various types of meteorographs are used, but the mean results of 10 years' work are practically identical. Instrumental and reduction errors are evidently not large, inasmuch as the agreement between near-by stations and between successive observations at the same station is close. All the evidence indicates that the probable error for temperature does not exceed 1° C.; for pressure it is about 4 mb. The effect of the latter in the determination of altitude in the lower levels is inappreciable, but at great heights, e.g., 20 kilometers, an error of 2 kilometers is possible. These errors are largely

[1] Geophysical Memoirs No. 13, Meteorological Office, London, 1919,. M. O. 220c, pp. 47-76.